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THE EFFECTS OF STREET NETWORK CONFIGURATION AND STREET-LEVEL URBAN DESIGN ON ROUTE CHOICE BEHAVIOUR:

An analysis of elementary school students walking to/from school in Istanbul

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ABSTRACT

This paper explores the association between the built environment, measured through street network configuration and street-level urban design, and route choice of children walking to/from school. The aim is to understand the extent to which student's actual route selections correspond with metric shortest routes and the role of spatial factors in explaining route choice in utilitarian walking.

Within this context, randomly selected students (ages 12-14) from five elementary schools in İstanbul, Turkey, were asked to draw their routes walking between home and school. Each student's route choice was modelled within a GIS database and metrically shortest routes between origins and destinations were identified by using the 'network analyst' tool. Street network configuration of the entire system was evaluated by using angular segment integration and choice analyses implemented in Depthmap as well as metric and directional reach implemented in GIS. Street-level urban design characteristics of the streets, including ground floor attractions, prevalence and width of sidewalks, street-level topography, street width (indicating street hierarchy), and existence of signalling/crossings, were evaluated through detailed field surveys and high quality satellite images.

The preliminary findings of this study imply that the configuration measures of street network may prove to be important variables for the description and modulation of human spatial behaviour in urban environments. More importantly, directional accessibility appears to play an important role as metric accessibility in route choice behaviour. However; the detailed analysis of selected routes indicates that the amount of ground floor attractions as well as certain street-level urban design qualities, such as sidewalk width, seem to be related to the preference of certain streets over and above others.

This study contributes to the literature by broadening our understanding of the environmental attributes associated with children's navigation choices in utilitarian walking. Findings augment

the knowledgebase that supports urban navigation by emphasizing the contribution of the spatial structure of the street network and the impacts of urban design qualities of the street environment.

KEYWORDS

Route choice, street network configuration, street-level urban design, utilitarian walking, İstanbul

1. INTRODUCTION

There is a considerable body of literature on walking behaviour and strategies pedestrians perform when navigating through the built environment. Yet route choice still remains one of the most interesting and challenging theoretical and practical problems in describing pedestrian travel. Investigating observed route choice behaviour is of utmost importance since the underlying decision-making process is more complex for route choice than for other travel choice dimensions (Spissu et al., 2011). This paper analyzes a database of 160 routes, collected by self-drawn maps by a sample of students from 5 different elementary schools in Istanbul, Turkey, to explore the association between the built environment, measured through street network configuration and street-level urban design, and route choice of children walking to/from school. The aim is to understand the extent to which student's actual route selections correspond with metric shortest routes and the role of spatial factors in explaining route choice in utilitarian walking.

Related literature has emphasized the importance of the urban environment in influencing navigation choices. Studies have shown that some proportion of the variation in path choice at decision points can be related to the metric distance (Seneviratne and Morrall, 1985) and some additional proportion of path choice is determined by urban design qualities of the street environment (Zacharias, 2001). Research examining pedestrian urban navigation argues that metric distance plays an important role and that people are inclined to choose the shortest route to minimize distance and walking time (Agrawal et al., 2008; Borgers and Timmermans, 2005). However, much research has also demonstrated that directness, as a topological structure of the street network, plays an important role as metric distance, and that directness is the most significant underlying factor in the selection of a particular route (Helbing, 2017). The significance of direction changes has also been underlined in the theory of space syntax, in accordance with the findings of spatial cognition indicating that direction changes, as an aspect of configuration, are related with the cognitive effort required to navigate through an area (Dalton, 2003; Jansen-Osmann and Wiedenbauer, 2004). Empirical evidence in space syntax studies suggests that the structure of an urban street network, as defined by the connectivity hierarchy measured by direction changes, plays an important role in pedestrian travel (Hillier and Iida, 2005; Ozbil et al., 2011). Furthermore, recent studies have shown that street network configuration is significantly related to recreational (Lee and Moudon, 2006a) as well as transportation (Ozbil and Peponis, 2012) walking behaviours.

However, a significant number of studies have shown that other route attributes, apart from metric or directional accessibility, are also important in route choice behaviour. Research investigating the urban design correlates of route choice has focused on the local qualities of the street environment often characterized in terms of street crossings, attractive landscaping, tree covers, and signalization (Agrawal et al., 2008; Cao et al., 2007), as well as aesthetic or safety features, such as cleanliness, interesting sights, and architecture (Appleyard, 1982; Gehl, 2011). One of the problems associated with the typical range of environmental attributes considered is the lack of consensus on the measures to be included in studies. For example, prior studies have reported conflicting and limited evidence on the effects of sidewalk availability for walking (Sallis et al., 1997). Findings with regard to land-uses, on the other hand, mostly agree that having destinations within walking distance from origins (homes, stations, schools, etc.) increase the odds of walking (Frank and Engleke, 2000; Guo, 2009; Handy and Clifton, 2001). The extent to which these route attributes play a substantial role in route choice behaviour depends

to a large extent on trip purpose (Bovy and Stern, 1990), i.e. scenery is very important for recreational trips, but it is not related to work-related walking trips. Other studies indicate that pleasantness (Bovy and Stern, 1990), pollution and noise levels, stimulation of the environment are important attributes in route selection (Brown et al., 2007; Hoogendoom and Bovy, 2004). A limitation with these factors is that it is very hard to quantify them into measurable variables to be used in quantitative studies. Moreover, it is difficult to utilize these subjective, intangible attributes in developing objective, tangible design and policy guidelines to create pedestrian oriented environments supportive of walking.

A second limitation of the analysis of children's spatial behaviour in urban settings, such as decision-making and choice behaviour while walking to/from school, is related to the kind of data and analytical tools available. The lack of actual routes travelled by students as well as measures to evaluate systematically the spatial structure of street network hinders in-depth research on choice behaviour during walking in real urban environments. As a result, simplifying assumptions about actual behaviour, i.e. appropriating the walked routes to shortest distance, have often been employed by studies (Agrawal et al., 2008). However, actual human spatial behaviour is far more complex than these assumptions, thus, more precise data and analytical measures/methods are needed to identify the underlying factors affecting route choice behaviour.

Another challenge is related to the unit of analysis used in characterizing the street environment. Related studies generally rely on environmental data, which is argued to affect decision-making in walking (i.e. street network connectivity, land-use diversity), at macro-level, such as census tracts or traffic-zone data. This prevents from identifying the associations of Modifiable Arial Unit problem in statistical correlations. Moreover, empirical evidence offered by these studies is still limited in terms of the specific urban design qualities related to walking behaviour of children. Studies on children's navigation patterns demonstrate that while certain environmental attributes, such as the presence of street trees and sidewalks, are commonly correlated with adults' and children's walking behaviour, other features, such as mixed land-use, may differ in their associations (Larsen et al., 2012).

This study fills these gaps within the literature by employing 3 sets of datasets containing detailed information of children's walking behaviour and the urban areas they are embedded in. First, it uses relatively accurate and comprehensive digital data sets of İstanbul metropolitan area obtained from the Municipality at the street-level accounting for fine-grained design aspects essential to measuring the street network configuration. Second, it examines street level urban design qualities in depth through detailed field surveys and high quality satellite images. Third, it is based on actual walking routes of children instead of relying on minimum cost routes. Hence, this study provides an opportunity for the analysis and theoretical understanding of decision making and choice behaviour of children in transportation walking.

2. METHODOLOGY

2.1 PARTICIPANT DATA

Five state elementary schools were identified as the case context. These schools were selected from five different districts of the Asian part of İstanbul, within neighbourhoods where walkers would have a mix of "well" and "less well" connected street segments, as well as both residential and mixed-use or commercial streets. Figure 1 illustrates the location of these schools. Randomly selected students (ages 12-14) from these elementary schools in İstanbul, Turkey, were asked to draw their typical routes walking between home and school on a detailed map of 1/5000 scale including street names, school's location, and important buildings/features. Each student was supported via a smart-phone-based street map when he/she was in doubt of the route. To ensure the accuracy of the drawn route starting points of their routes were compared with their geocoded addresses. A 90% match was obtained with students' geocoded addresses and the starting points they drew on the maps. This age group was targeted since arguably they are relatively more conscious of their decision making process.

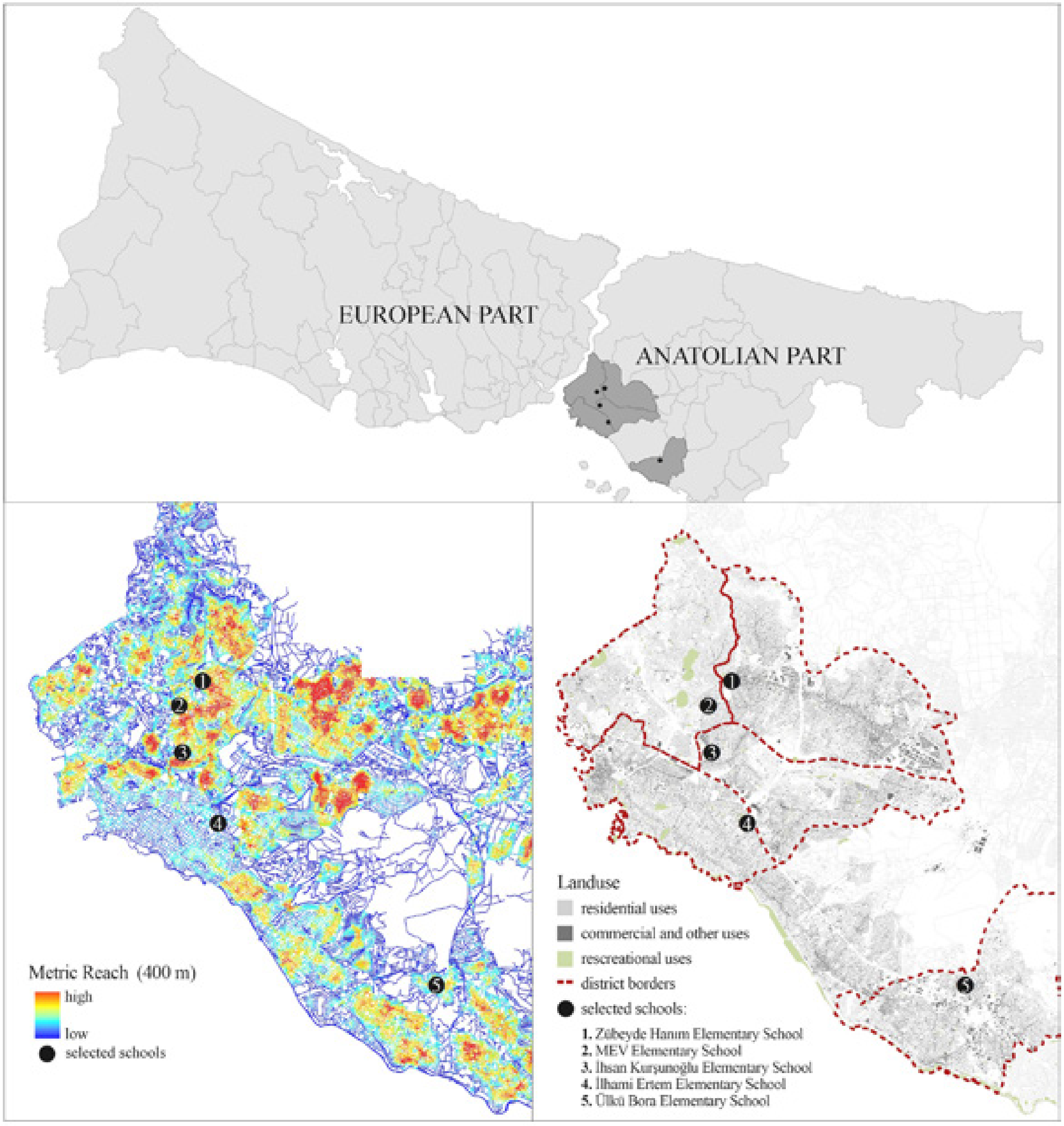

Figure 1 - Location of surveyed schools on the overall map of Istanbul and on maps showing street network configuration coded against metric reach (400m)[1] and land uses coded against residential, recreational commercial and other uses.

2.2 PATH CHOICE

Actual routes. Each student's actual route was entered into a GIS database and actual distances walked along the network were calculated. The mean trip distance was 749 meters, with the shortest trip being 53 meters and the longest 1.94 kilometers (Figure 2). Looking at the distance data broken into quartiles shows that a quarter of respondents walked a half a kilometer or less, the next quartile walked between half a kilometer and a three-fourth of a kilometer, the third quartile walked between three-fourth and a kilometer, and the final quarter walked over a kilometer.

1 Metric reach (400m) measures the total length of streets starting from the midpoint of each street segment and extending in all directions within a 400 meters threshold.

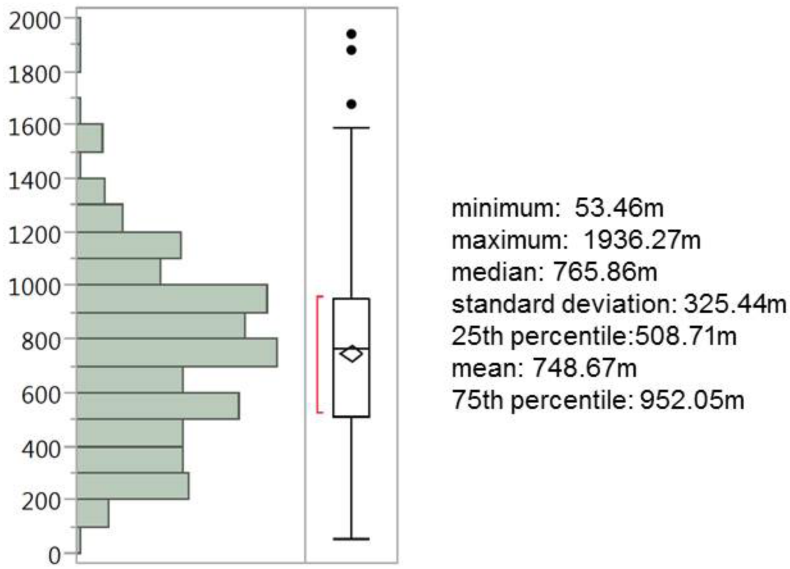

Figure 2 - Distribution of distances walked along the network across schools.

The difference between the actual and *the potential*. This study is interested in studying the underlying environmental reasons affecting decision making in walking. The emphasis is on answering the question why some segments were actually selected by the participants and why those, though lying on the metrically shortest routes, were not selected. Thus, metrically shortest routes on the network between origin and destination pairs were identified using the 'network analyst' tool. Figure 3 shows the actual routes for the entire participants at Ulku Bora elementary school overlaid against their metrically shortest counterparts. As seen in the figure, though there are some overlaps between the actual selection and the metrically shortest segments, there are also major differences. Street segments were computed as a function of the frequency of actual selection versus the frequency of potential selection as metrically shortest segment. For example, a street segment may have been selected 5 times during actual navigation, yet its shortest segment rate may be 2 (this segment may serve as the metrically shortest segment lying along 2 different routes). Or a street segment may not have been selected at all, but it actually may lie as the metrically shortest segment along 4 different routes. Figure 4a illustrates these hypothetical cases and Figure 4b demonstrates an actual case.

Figure 3 - Self-drawn routes (continuous, dark red lines) compared with their metrically shortest routes (dashed, pink lines) for Ulku Bora elementary school. Dark grey buildings represent commercial activities.

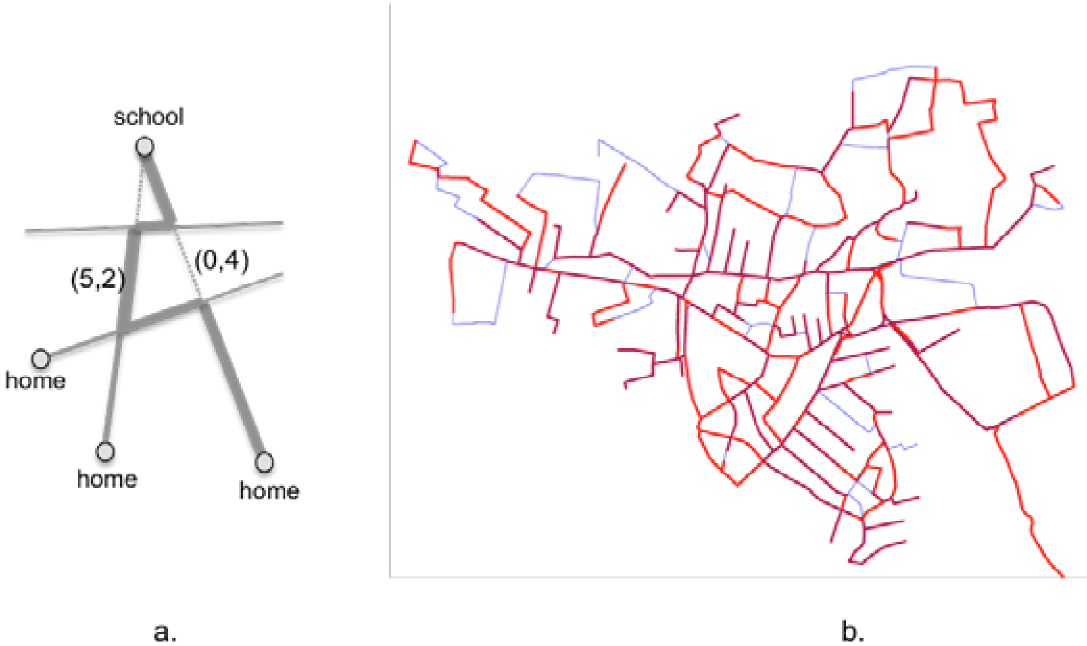

Figure 4 - Comparison of selected street segments with their metrically shortest counterparts. (a) Hypothetical case: the first number in parentheses indicates the frequency of selection during actual navigation by participants; the second number represents the rate of the segment in lying along metrically shortest routes. (b) Actual case: red and blue indicate actual and metrically shortest segments along walked routes.

The differences between the frequencies of segments were quantified (a-b, where a is the frequency of actual selection, AS, and b is the potential frequency of metrically shortest segment, SS). For example, if a segment is part of a shortest route for 10 different journeys (b=10) but is selected only 5 times (a=5), then the difference between the frequencies is -5. Or if a segment is not part of any shortest route (b=0) but is actually selected by 10 students, then the difference between the frequencies is 10. Multivariate regression models were developed estimating the difference between the frequencies of the actual selection (a) and the frequency of the potential selection (b) to identify the underlying built environment attributes affecting route choice. Those segments having a difference greater than or equal to 5 were selected to be statistically modelled and studied further since they indicate a consistent pattern of preference. Lastly, those segments with the highest (top 10%) differences between their frequencies were compared with their shortest counterparts through images and numbers.

2.3 STREET NETWORK CONFIGURATION

Street network configuration of the entire system was evaluated by using angular segment integration and choice analyses implemented in Depthmap as well as metric and directional reach implemented in GIS. The decision to include different measures is motivated by the variety of configurational qualities (metric, geometric and topological) captured by each measure. Segment angular integration measures the number of direction changes needed to move from each street line to all others measures within a set radius using the least angle measure of distance. Segment angular choice which measures how many times a space is selected on journeys between all pairs of origins and destinations (Hillier and Iida, 2005). In other words, integration measures how easy it is to access one space (road segment) from all others in the network; whereas choice measures how likely it is for a space to be selected moving from one space to another in the network (Hillier and Iida, 2005). These two measures represent the to and *through* movement potentials of the street segments (Hillier et al., 2012).

Street network configuration of the entire region was evaluated by using two parametric measures of connectivity (Peponis et al., 2008), which offer a systematic framework through which to evaluate street connectivity from two points of view: metric accessibility and density on the one hand, and directional accessibility on the other. Metric reach captures the density of streets and street connections accessible from each individual road segment. This is measured by the total street length accessible from each road segment moving in all possible directions up to a parametrically specified metric distance threshold. Directional reach measures the extent to which the entire street network is accessible with few direction changes. This is measured by the total street length accessible from each road segment without changing more than a parametrically specified number of directions. While metric reach extends uniformly along the streets surrounding a given road segment, directional reach may extend much less uniformly, because it is sensitive to the shape and alignment of streets, not merely to their density. The inclusion of directional reach in the analysis is a direct response to the research findings suggesting that the distribution of pedestrian movement may have cognitive dimensions associated with it.

Integration was calculated for radius n while choice and metric reach were computed for 400m. distance threshold since the selection of routes within this study spread over an area of 400 meters radii. Directional reach was computed for two direction changes subject to a 20° angle threshold. The 20° angle threshold was selected to set the threshold low enough to make the analysis sensitive to street sinuosity. Computing directional reach for two direction changes provides an estimate of how well a street segment is embedded in its surroundings from the point of view of directional distance. These configurational measures are similar to the syntactic measures of integration and choice in that they take angle of direction change into account, yet they differ in that they are inherently parametric: one can vary what rotation angle counts as a direction change. Metric reach and directional reach function as measures of street connectivity that can discriminate between proximate street segments, capturing the spatial structure of an area.

2.4 STREET-LEVEL URBAN DESIGN

Street segments were evaluated in terms of urban design characteristics that are shown to affect navigation in urban environments through their impacts on pedestrians' perceptions. Street-level attributes include ground floor attractions (number of residential, commercial –retail, office, catering–, other non-residential land-uses, and recreational uses opening directly on each individual street segment relativized by 100 meters), prevalence and average width of sidewalks, street-level topography, and existence of signalling/crossings, were evaluated through detailed field surveys and high quality satellite images. Sidewalk maintenance was not factored in since almost all sidewalks surveyed offered a moderate to good quality.

3. RESULTS

3.1 STATISTICAL ANALYSIS

Table 1 demonstrates the results for 3 different linear regression models estimating the difference between the frequency of selection of the walked segment and the frequency of potential selection as its shortest counterpart. When street connectivity measures are included only, all measures, except for global integration are positively and significantly correlated with the output variable. Metric reach (400m) and directional reach (2 direction changes, 200) remain significant across models while choice (400m) loses its significance once other variables are considered. Surprisingly, integration (n) becomes significant (99%) only within the overall model. Street connectivity measures explain 20% of the variation in the differences between selection frequencies. Adding land use variable to the model results in a considerable increase in the predictive power of the model (R2 change=16%). In terms of land use variables, number of residential (negative) and commercial (positive) buildings is significantly (%95 and %99 respectively) correlated with the difference in frequencies of selection of actual segment and its metrically shortest counterpart. In other words, the higher the number of commercial land uses (i.e. shops, stores, banks, etc.), and the lower the number of residential uses opening onto the street, the more likely a student is to choose that segment instead of its metrically shortest counterpart. From street-level urban design factors, street width and average sidewalk width variables appear to be positive correlates (99% and 95% respectively) of segment choice. In fact, when standardized coefficients within the overall model are compared, it is found that the width of the street segment is the most significant variable related to decision making in pedestrian navigation. Since street width is an indicator of street hierarchy, it can be concluded that through streets with wider sidewalks, instead of local streets with relatively narrower sidewalks, are preferred by students. The overall model explains about 50% of the variation in the output variable.

	β	|t|	std β	β	|t|	std β	β	|t|	std β
constant		1.49			3.36*			4.51	
Street Network									
integration(n)	-0.00	0.23	-0.02	0.00	1.72	0.14	**0.00**	**2.86**	**0.22**
choice (400m)	0.00	3.15	0.25	0.00	1.60	0.03	0.00	1.24	0.09
metric reach(400m)	**2.15**	**3.48**	**0.25**	**0.31**	**4.02**	**0.28**	1.64*	3.18*	0.20*
directional reach (2,200)	**4.83**	**3.68**	**0.28**	3.51	2.83	0.18	2.41	2.06	0.13
Land Use									
#residential/100m				-0.76*	3.35*	-0.24*	-0.44	1.93	-0.14
#commercial/100m				**0.83**	**4.36**	**0.28**	0.34*	3.02*	0.23*
#nonresidential / 100m				-0.43	0.81	-0.06	-0.61	1.21	-0.08
#recreational/100m				-0.37	0.19	-0.01	-1.26	0.69	-0.05
Street-Level Attributes									
topography							-0.20	0.17	-0.01
sidewalk prevalence∞							1.51	1.00	0.07
avg. sidewalk width							0.01	2.05	0.16
street width							**0.01**	**3.68**	**0.30**
traffic safety∞∞							1.81	0.97	0.06
N					160				
R2		**0.19**			**0.35**			**0.52**	
adjusted R2		**0.17**			**0.32**			**0.47**	

Table 1 - Multivariate regression models estimating the difference between the frequency of selection of the walked segment and the frequency potential of selection of its shortest counterpart.

bold $p<0.001$; *$p<0.01$; italic $p<0.05$, 2 tailed tests

∞ existence of sidewalk on one side only=1; existence of sidewalk on both sides=2; otherwise=0

∞∞ existence of pedestrian crossings/traffic lights=1; otherwise=0

3.2 SEGMENT-BASED ANALYSIS

In order to better understand the underlying factors related to route choice, those segments with the highest (top 10%) differences between their actual and potential frequencies of selection were studied further. All actual routes that were supposed to entail those segments between origin and destination pairs were overlaid together. Segments diverged distinctively from their shortest counterparts were analysed in detail through images and numbers. The aim is to clarify why some segments were actually selected by the participants and why those, though lying on the metrically shortest routes, were avoided. Figures 5-9 illustrate paths passing through those segments and identify the environmental factors underlying the differentiation in selections.

Figure 5 - Routes passing from segments that have highest differences in their frequencies of selection – both actual (walked segments, shown in red) and potential (their metrically shortest counterparts, shown in blue) for Ilhami Ertem elementary school located in Kadikoy.

Figure 6 - Routes passing from segments that have highest differences in their frequencies of selection – both actual (walked segments, shown in red) and potential (their metrically shortest counterparts, shown in blue) for MEV elementary school located in Uskudar.

Figure 7 - Routes passing from segments that have highest differences in their frequencies of selection – both actual (walked segments, shown in red) and potential (their metrically shortest counterparts, shown in blue) for Ihsan Kursunoglu elementary school located in Atasehir.

Figure 8 - Routes passing from segments that have highest differences in their frequencies of selection – both actual (walked segments, shown in red) and potential (their metrically shortest counterparts, shown in blue) for Zubeyde Hanim elementary school located in Umraniye.

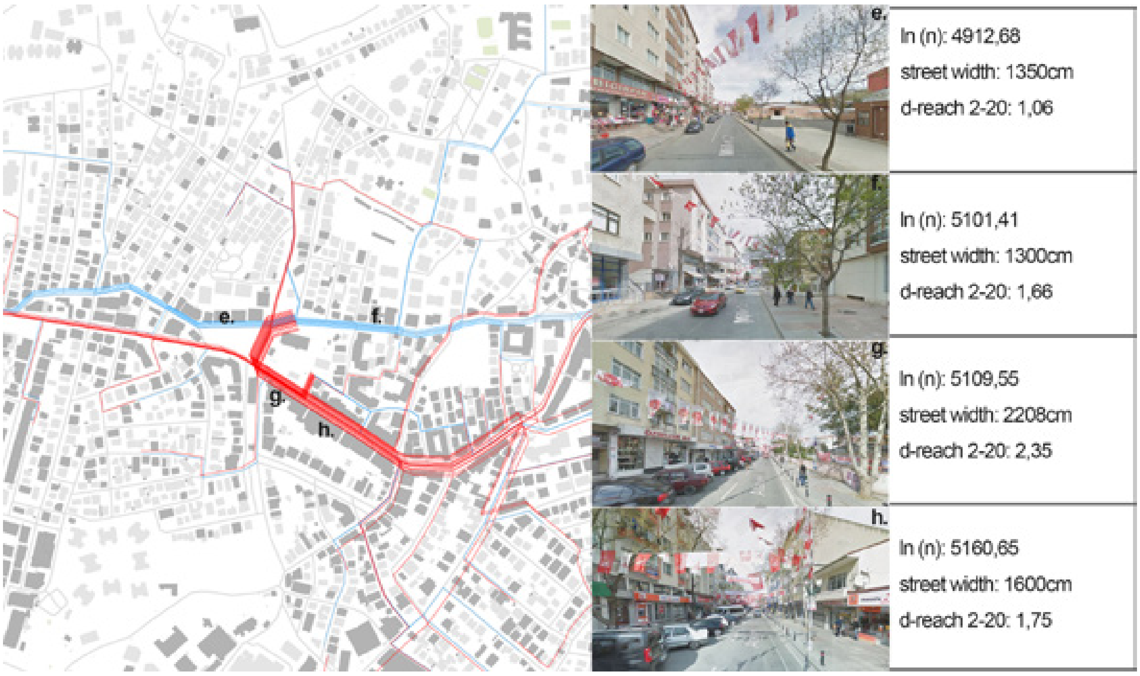

Figure 9 - Routes passing from segments that have highest differences in their frequencies of selection – both actual (walked segments, shown in red) and potential (their metrically shortest counterparts, shown in blue) for Ulku Bora elementary school located in Kartal.

Figure 5 compares routes walked between homes and Ilhami Ertem elementary school located in Kadikoy with their metrically shortest counterparts. Snapshots and numbers from segments indicate that students prefer to choose to walk on segments with higher number of commercial activities, increased street width and average sidewalk width. In MEV elementary school located in Uskudar (Figure 6), when the segments of actual selection and their metrically shortest counterparts are analysed, it is found that segments with higher directional accessibility, increased number of commercial activities and average sidewalk width are selected. Similarly, routes walked for Ihsan Kursunoglu elementary school located in Atasehir indicate a preference for street segments with higher *through* and *to* movement potentiality and wider sidewalks (Figure 7). Observations from Zubeyde Hanim elementary school in Umraniye demonstrate that students' decision making in urban navigation is affected by to movement potentiality and metric accessibility of segments along with number of commercial activities opening directly onto the street (Figure 8). Lastly, a comparison between actual and potential routes in Ulku Bora elementary school in Kartal displays similar results; students chose to walk on segments with higher global integration and directional reach values and with wider sidewalks (Figure 9). Hence, these snapshots indicate that regardless of location within the city, there are a few underlying street network and street-level urban design factors shaping route selection. However, it can be observed from these figures that spatial structure of street network becomes the more so dominant factor affecting route choice in neighbourhoods located further from the centre than for neighbourhoods located within the city centre, where street-level urban design attributes, such as sidewalk and street width and number commercial activities, play a more significant role in route choice.

4. STUDY FINDINGS AND THEIR IMPLICATIONS FOR DESIGN AND PLANNING

This study asked students to draw on detailed maps their typical routes walking between home and school in 5 schools in different districts to identify how far they walked and the actual routes followed. Route environment for street segments that showed variability in actual selection versus metrically shortest potentiality was measured through detailed field observations and secondary data. Linear regressions were developed to determine the built environmental

factors underlying the differences in selection. Lastly, in-depth comparisons were made between the actual walked segments and their metrically shortest counterparts to untangle possible correlates of students' choice of routes. The findings indicate important conclusions that have important implications for planners and policy makers focused on improving the built environment for pedestrians.

The results suggest that spatial structure of the street network and street-level urban design attributes work together to shape students' decision making in targeted urban navigation. Metric accessibility, potentiality of accessing multiple destinations from a street segment, as well as directional accessibility, the ease of accessing the entire street network from a street segment, defined through the metric and topological structure of the urban network, are significant correlates of segment choice. In other words, if there is a higher density of intersections and lower number of direction changes along a path, students are more likely to take that path, rather than following the metrically shortest route. From a theoretical point of view, this implies that urban navigation strategies in targeted-walking are more related to the topo-geometric properties of the street network rather than the metric or geometric properties alone. From a design policy point of view, designing better connected street networks with reduced directional distance between home and school might serve as inducement for navigation choices and walking behaviour.

The street level urban design affects segment decision primarily through attractions (commercial land uses and through streets) and barriers (sidewalks). Both the multivariate regression models and individual analyses of paths indicate that students prefer to walk on through streets with wider sidewalks rather than local ones with relatively narrower sidewalks. However, according to linear models, average sidewalk width plays an important but smaller role in path choices compared to other urban design factors. Higher levels of commercial land uses opening onto the streets appear to have associations with students' selection of a particular street segment rather than its shortest counterpart. This supports the findings of various studies highlighting the significance of the availability of non-residential destinations nearby pedestrian-oriented nodes, such as schools and transit stations in walking behaviour (Cervero, 2002; Lee et al., 2013). Residential land-use types play an important role but with a "deterring" instead of an "encouraging" effect.

In short, these results suggest that improved street-level urban design conditions along routes between home and school will attract more students to select those paths during pedestrian navigation, and will, in return, encourage children to walk to/from school. More importantly, this study emphasizes the significance of spatial structure of street network in affecting navigation choices. Findings augment the knowledgebase that supports urban navigation by emphasizing the contribution of the spatial structure of the street network, as significant as the impacts of urban design qualities of the street environment. The results also contradict certain literature which argues that the primary consideration in choosing a route is minimizing time and distance (Seneviratne and Morrall, 1985). In-depth analysis presented in this paper demonstrate that in targeted walking, such as walking regularly to/from school where it is assumed that the person has full knowledge of the potential routes between origin and destination, including the shortest one, the pedestrian still prefers to walk longer distances in favour of certain route attributes.

In addition, the descriptive analysis of walking distances for five elementary schools point to the fact that students walk considerably farther to access schools than commonly assumed. Conventional school environmental scale among planners is quarter of a mile (~400meters) (McMillan, 2007; Olson, 2010). This threshold is also recommended by Clarence Perry (1929) and Barton, Grant and Guise, (2003). The results of this study suggest quite a different reality, at least for walk trips to/from schools in Istanbul, Turkey. Half the students surveyed walked around 750 meters to access the school (the median trip distance was 766 meters). This result indicates that planners and designers laying out pedestrian-oriented developments around elementary schools can assume that many students will be willing to walk considerably farther to/from school than they may have previously thought.

Overall, the study results suggest that planners and policy makers aimed to encourage walking should focus on creating direct and dense connections between activities (i.e. between residential and commercial uses) and a connected street network with more direct connections between origin-destination nodes around schools. In fact, it may be that designing through streets with relatively wider sidewalks and increased commercial activities should be the key focus for designers since these often feel safe to both students and caregivers.

5. STUDY FINDINGS

In addition to lessons for practicing designers and planners, this study suggests several avenues for further research both on how to conduct environmental analyses and surveys related to students' path choices and additional research topics related to the impact of the built environment on pedestrians.

A first key finding about statistical analyses related to walking is that compared to analyses and measures at larger-units (i.e. zones, census tracts), the segment-based analyses and measures are more sensitive to built environment differences even within the same neighbourhood. Thus, future research needs to employ detailed on-site field observations and street connectivity measures at the street segment level, instead of using aggregate built environment data. The availability of spatially disaggregated data also makes individual-based spatial analysis feasible. In addition, as Guo (2009) argues, "Compared with modal choice, path choice is less likely to correlate with job and housing location choices." It is reasonable to assume that students studying at the same school share a similar attitude and preference towards traveling between home and school. Hence, the analyses conducted here seem to avoid the self-selection problem and to address the challenge of causality. Route choice has been widely used in transportation planning (Broach et al., 2012; Cats et al., 2011), but has rarely been used in a built environment-walking study (Lee and Moudon, 2006b).

Another important finding related to pedestrian survey design is that asking respondents to trace their walking route on a local map—a relatively untested method in walk trip research—works well. For this study, it was unsure whether respondents would be willing to provide this information or if they would fill out the map clearly so that the data would be useful. The study results show that the survey technique is highly effective. Out of 432 students who indicated walking as mode of transport between home and school, 390 traced their routes legibly (a 90% completion rate). Since the surveys were conducted face-to-face, these route tracings between the exact street addresses of home and school were precisely drawn on detailed maps with the help of smart-phones when it was necessary and the research team could easily transfer these routes into a GIS database. This technique provides opportunities for the analysis and understanding of disaggregate human spatial behaviour. The only drawback is that it prolongs survey time significantly.

The study can also be expanded further with additional analyses. One useful elaboration of the research described here would be to track participants, here students, using GPS devices to avoid relying on the memories of children, and thus, to acquire more precise data. During tracking, social information regarding walking behaviour, such as whether the child is walking alone or with an adult, can be obtained and interpreted as an input to decision making. Another useful approach would be to survey participants after or during their walking trips to get first-hand information on their route choice preferences. For example, participants can be asked to indicate the locations they avoided. Such a survey has been conducted in Schlossberg et al.'s study (2007). Surveys may also help validate the findings of the comparative analysis as described here. Revealing route choices and route avoidance by pedestrians may offer planners and policy makers useful guidelines in designing interventions to create walkable neighbourhoods.

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REFERENCES

Agrawal, A. W., Schlossberg, M., and Irvin, K., (2008), How far, by which route and why? a spatial analysis of pedestrian preference, *Journal of Urban Design*, 13(1), 81–98.

Appleyard, D., (1982), *Livable streets,University of California Pres*s. Berkeley.

Barton, H., Grant, M., and Guise, R., (2003, October 18),Shaping neighbourhoods: a guide for health, sustainability and vitality. London: Spon Press. Retrieved from http://discovery.ucl.ac.uk/92896/

Borgers, A., and Timmermans, H., (2005), Modelling pedestrian behaviour in downtown shopping areas,In 2005. London, United Kingdom: 10th International Conference on Computers in Urban Planning and Urban Management.

Bovy, P., and Stern, E., (1990), *Route choice: wayfinding in transport networks*, (K. A. Publishers, Ed.). Dordrecht.

Broach, J., Dill, J., and Gliebe, J., (2012), Where do cyclists ride? A route choice model developed with revealed preference GPS data,*Transportation Research Part A: Policy and Practice*, 46(10), 1730–1740.

Brown, B. B., Werner, C. M., Amburgey, J. W., and Szalay, C., (2007), Walkable route perceptions and physical features: converging evidence for en route walking experiences,*Environment and Behavior*, 39(1), 34–61.

Cao, X., Mokhtarian, P. L., and Handy, S. L., (2007), Do changes in neighborhood characteristics lead to changes in travel behavior? a structural equations modeling approach,*Transportation*, 34(5),

Cats, O., Koutsopoulos, H., Burghout, W., and Toledo, T., (2011), Effect of real-time transit information on dynamic path choice of passengers,*Transportation Research Record: Journal of the Transportation Research Board,* 2217, 46–54.

Cervero, R., (2002), Built environments and mode choice: toward a normative framework,*Transportation Research Part D: Transport and Environment*, 7(4), 265–284.

Dalton, C., (2003),The secret is to follow your nose: route path selection and angularity,*Environment Behavior*, 35, 107–131.

Frank, L. D., and Engleke, P., (2000), *How land use and transportation systems impact public health : a literature review of the relationship between physical activity and built form,Environments*. Atlanta, GA.

Gehl, J., (2011), *Life between buildings: using public space*. Island Press.

Guo, Z., (2009), Does the pedestrian environment affect the utility of walking? a case of path choice in downtown Boston,*Transportation Research Part D: Transport and Environment,* 14(5), 343–352.

Handy, S., and Clifton, K., (2001), Local shopping as a strategy for reducing automobile travel,*Transportation*, 28(4), 317–346.

Helbing, D., (2017), *Traffic dynamics: new physical modeling concepts*, (Springer-Verlag, Ed.). Berlin.

Hillier, B., and Iida, S., (2005), *Network effects and psychological effects: a theory of urban movement*.

Hillier, B., Yang, T., and Turner, A., (2012), Analysis of city space analysis of city space,*Journal of Space Syntax*, 3(2), 155–193.

Hoogendoom, S. P., and Bovy, P., (2004), Pedestrian route-choice and activity scheduling theory and models,*Transportation Research Part B: Methodological*, 38(2), 169–190.

Jansen-Osmann, P., and Wiedenbauer, G., (2004), The Influence of Turns on Distance Cognition: New Experimental Approaches to Clarify the Route-Angularity Effect,*Environment and Behavior*, 36(6), 790–813.

Larsen, K., Gilliland, J., and Hess, P. M., (2012), Route-Based Analysis to Capture the Environmental Influences on a Child's Mode of Travel between Home and School,*Annals of the Association of American Geographers*, 102(December 2014), 1348–1365.

Lee, C., and Moudon, A. V., (2006a), Correlates of walking for transportation or recreation purposes,*Journal of Physical Activity & Health*, 3, 77–98.

Lee, C., and Moudon, A. V., (2006b), The 3Ds+R: Quantifying land use and urban form correlates of walking,*Transportation Research Part D: Transport and Environment*, 11(3), 204–215.

Lee, C., Zhu, X., Yoon, J., and Varni, J. W., (2013),Beyond distance: children's school travel mode choice.,*Annals of Behavioral Medicine : A Publication of the Society of Behavioral Medicine*, 45(1), 55-67.

McMillan, T. E., (2007), The relative influence of urban form on a child's travel mode to school, *Transportation Research Part A: Policy and Practice*, 41(1), 69–79.

Olson, J., (2010), *The neighbourhood unit: how does concept apply to modern day planning*. Texas : EVstudio Colorado & Texas Architects & Engineers.

Ozbil, A., and Peponis, J., (2012), The Effects of Urban Form on Walking to Transit, *Eigth International Space Syntax Symposium*, 1–15.

Ozbil, A., Peponis, J., and Stone, B., (2011), Understanding the link between street connectivity, land use and pedestrian flows, *Urban Design International*, 16(2), 125–141.

Peponis, J., Bafna, S., and Zhang, Z., (2008), The connectivity of streets: reach and directional distance, *Environment and Planning B: Planning and Design*, 35(5), 881–901.

Perry, C., (1929), The neighborhood unit, In *The Urban Design Reader* (54–65).

Sallis, J. F., Johnson, M. F., Calfas, K. J., Caparosa, S., and Nichols, J. F., (1997), Assessing perceived physical environmental variables that may influence physical activity., *Research Quarterly for Exercise and Sport*, 68(4), 345–351.

Schlossberg, M., Agrawal, A. W., Bekkouche, V. L., and Irvin, K., (2007), *How far, by which route, and why? a spatial analysis of pedestrian preference*.

Seneviratne, P., and Morrall, J., (1985), Analysis of factors affecting the choice of route of pedestrians, *Transportation Planning and Technology*, 10(2), 147–159.

Spissu, E., Meloni, I., and Sanjust, B., (2011), Behavioral analysis of choice of daily route with data from global positioning system, *Transportation Research Record: Journal of the Transportation Research Board*, 2230, 96–103.

Zacharias, J., (2001), Pedestrian behavior and perception in urban walking environments, *Journal of Planning Literature*, 16(1), 3–18.